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Recovery of Spectrally Overlapping QPSK Signals Using a Nonlinear Optoelectronic Filter

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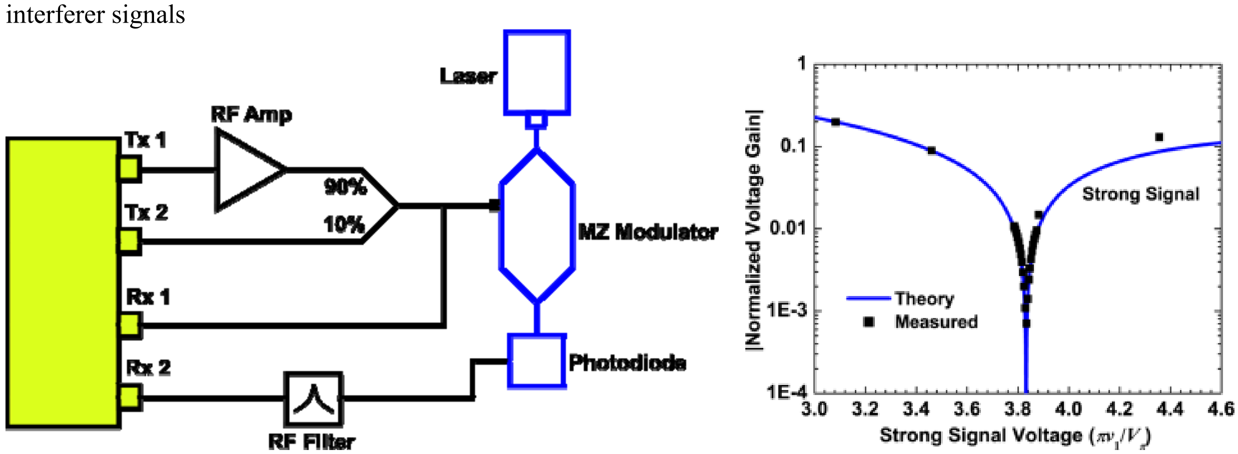
Abstract: We demonstrate recovery of a weak QPSK signal buried 35-dB beneath an interfering QPSK signal having an overlapping spectrum. This nonlinear optoelectronic filter technique opens new directions to increase spectral efficiency.

OCIS codes:

1. Introduction

The ability to separate and recover the information conveyed in a weaker signal buried beneath a stronger interfering signal remains one of the holy grails in the field of communications. The detection of this information is especially challenging when the frequency separation of the weaker and stronger signal approaches zero such that their information bands share significant spectral overlap. The solution to this problem has the potential to impact many real-world systems such as (1) those systems that could exploit the ability to send and detect information covertly hidden beneath a strategically placed interferer, as well as, (2) satellite or ground-based communications systems that could benefit from spectral reuse, (3) systems that could make use of technology allowing simultaneous transmit and receive (STAR), (4) systems that require the recovery of a signal that has been jammed, and (5) radar systems that could benefit from increased detection sensitivity.

Here, we demonstrate an optoelectronic filter that enables the detection of a desired signal hidden beneath a large-signal interferer having an overlapping or nearby spectrum that is not only located in close frequency proximity to the desired signal but is also larger in magnitude by >35 dB. We combine this filter, reported previously in Refs. [1, 2], with a novel algorithm to recover the quadrature phase-shift keyed (QPSK) modulated information contained within the desired signal. At the time of developing this technique, we became aware of Ref. [3], which proposed an alternative algorithm to determine the minimum-shift keyed information stored in a desired signal with the dual restriction that the signal and interferer are collocated at the same frequency and also that the information of the interferer is known beforehand separate from the desired signal. The power of our technique stems from the fact that it requires no *a priori* knowledge of either of the two signals for its signal extraction, that it maintains functionality for use on signals employing higher-order modulation formats such as QPSK as demonstrated here, and that it operates for arbitrary frequency separation between the desired and interferer signals



(a) (b)

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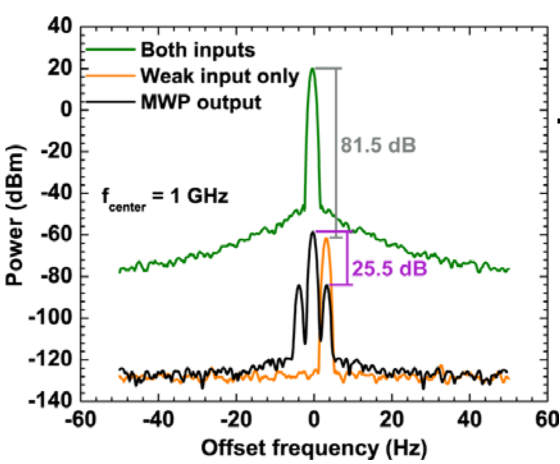
Figure 1: (a) System diagram showing two transmitted signals that are QPSK modulated and combined and sent to an optoelectronic filter and later to an ADC for signal processing. (b) Filtering of the interferer signal transmission dependent on reaching $V = 3.83*V_{\pi}/\pi$ [].

2. Results

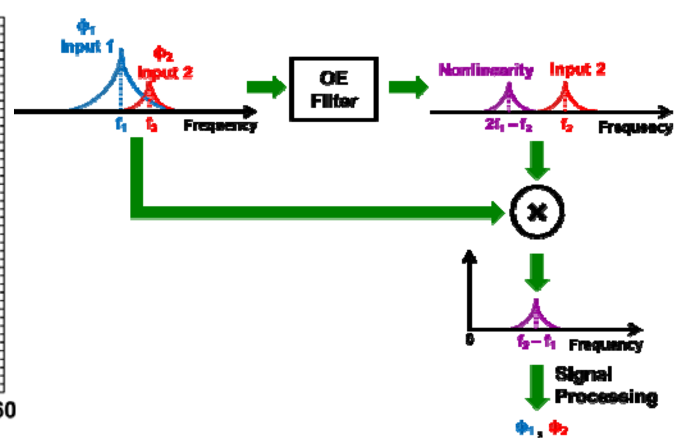
The diagram of our system demonstration is shown in Fig. 1(a), which depicts two signals, Tx 1 and Tx 2, transmitted by an Analog Devices AD9361 2-channel transceiver. One signal (Tx 1) serves as the interferer (centered at 3 MHz), while the other (Tx 2) assumes the role of the desired signal (also centered exactly at 3 MHz) with 35 dB relative amplitude difference between the two. Both signals are upconverted to 2.5 GHz prior to signal transmission. We note that although the two signals are separated by zero frequency in our demonstration here, we have shown the successful filtering of the interferer and demodulation of the desired signal for a variety of center frequencies, as well as, separation frequencies. We apply a pseudo-random 30 Kbaud QPSK sequence to each of the signal channels and subsequently combine both signals onto a single channel for input to the optoelectronic filter. Separate to this, we also split off part of the combined signal and send the output to Rx 1 of the Analog Devices transceiver board for conversion to the digital domain. The optoelectronic filter is a conventional microwave photonic link [4] (i.e., CW laser (P_{out} = 30 mW), Mach-Zehnder modulator (V_{π} = 2.5 V) and a photodetector) that is driven well beyond the typical linear operating range. When the link is driven by a signal having amplitude $V = 3.83*V_{\pi}/\pi$ the link gain decreases to approximately zero for only the signal that reaches the nulling amplitude [1]. Since this signal filters based on reaching a specific amplitude, the optoelectronic filter enforces all signals that maintain the constant amplitude $V = 3.83*V_{\pi}/\pi$, but otherwise may have phase- or frequency-modulated information, to become rejected. Fig. 1(b) shows this rejection of a large interferer signal based on its amplitude.

Fig. 2(a) shows an experimental measurement where two signals are combined and sent as input into an optoelectronic filter. Both signals contain no modulated information. The interferer which is centered at 1 GHz (0 Hz offset frequency) masks the presence of the desired signal (green trace), which is located at +3.5 Hz offset from the interferer. When the interferer is turned off, the desired signal appears at a level 81.5 dB below the large-signal interferer (orange trace). However, after passing both signals through the optoelectronic filter, the interferer because suppressed by 81.5 – 25.5 = 56 dB relative to the desired signal thus unmasking its presence (black trace). A third signal is generated on the side at a frequency 1 GHz – 3.5 Hz due to the filter's nonlinearity. The key challenge to overcome of the optoelectronic filter is the generation of a third-order nonlinear intermodulation spur in the band of the desired signal at frequency $2f_1 - f_2$. For Fig. 2(a), this intermodulation spur occurs at -3.5 Hz offset frequency. This nonlinearity is removed in our implementation by processing the output of the nonlinear filter in the digital domain, to be described next.

The process flow of our algorithm is depicted in Fig. 2(b). We first multiply the digitized optoelectronic filter output by the signal path that was instead directly sent to the ADC. This allows us to translate both the desired signal and the nonlinear intermodulation spur down to baseband. Once at baseband, the nonlinear spur constructively adds to the desired signal, creating a single mixed signal comprising both the phase information of the desired signal and of the interferer. At this point, we use the ADC channel that bypassed the optoelectronic filter to detect the phase

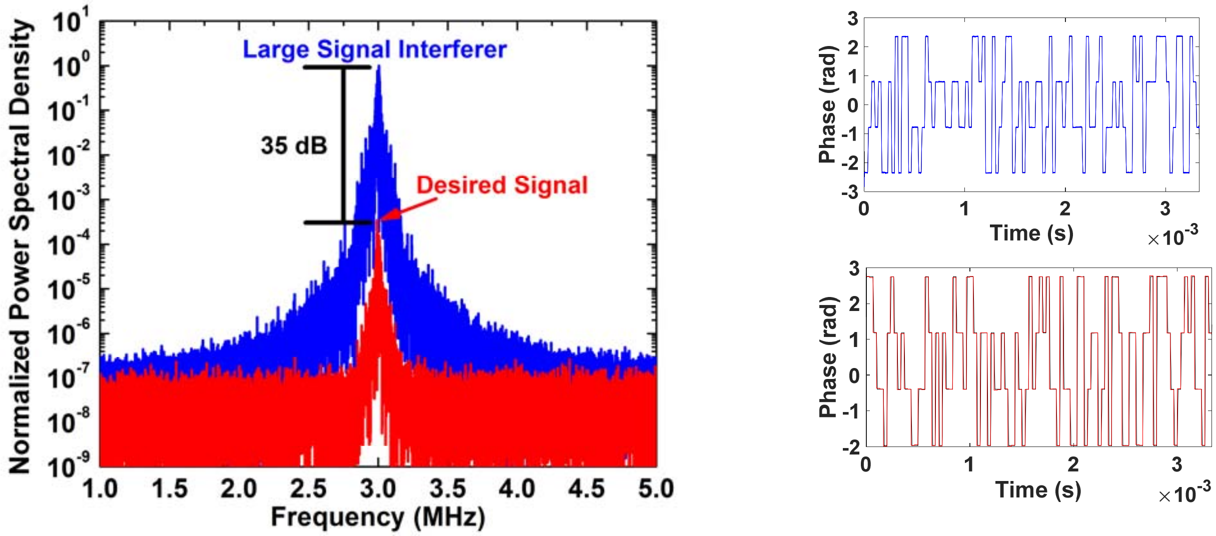


(a)



(b)

Figure 2: (a) Optoelectronic filter output showing the suppression of a large-signal interferer relative to a small desired signal by 56 dB. The desired signal is initially 81.5 dB below the large-signal interferer and is buried beneath the phase noise of the interferer (after Ref. [1]). (b) Process flow for demodulating the information of the smaller desired signal through downconversion to baseband.



(a) (b)

Figure 3: (a) Spectrum of a large signal interferer and a desired signal that is located 1 MHz away and is 35 dB lower in relative amplitude. (b) Transmitted and recovered interferer and desired signal QPSK sequences, demodulated using the optoelectronic filter.

information of the interferer. Finally, combining the information of the interferer with the information contained within the mixed signal, we are able to uniquely determine the QPSK modulation carried by the desired signal. We emphasize that our signal extraction technique acts only on the total input presented to the ADC and thus requires no knowledge of each of the individual transmitted channels in isolation.

Fig. 3(a) shows the spectrum of the pseudo-random QPSK inputs uniquely applied to each of the individual desired signal and interferer signal channels. As can be observed from the spectrum, the desired signal is offset from the large signal interferer by exactly zero frequency and is also 35 dB lower in relative amplitude. The two signals are upconverted to 2.5 GHz before the signals are combined and transmitted to the optoelectronic filter. The higher order harmonics after the optoelectronic filter are removed using an RF filter, and then sent to an ADC for processing. During our measurements, the frequency and amplitude of the desired and interferer signals were varied to span the range of lower frequencies and also to verify the operation of our algorithm when both signals are separated in frequency.

Fig. 3(b) shows the ideal pseudo-random QPSK signals that are modulated on each of the interferer and desired signals. In addition to the ideal QPSK signals, the recovered signals for both inputs are overlaid on top. The information of the interferer was extracted via direct IQ demodulation using the channel that bypassed the optoelectronic filter, and this information was then used to assist the demodulation of the desired signal. As is expected, the interferer reconstruction is nearly perfect since its amplitude is dominant over the weaker desired signal nearby by over 35 dB. However, we also see that the desired signal recovery is also nearly ideal and clearly identifies each of four phase-modulated levels.

We reported here an optoelectronic filter along with a novel algorithm that when combined provides a potentially powerful solution to the problem of separating and recovering signals that occupy overlapping frequency spectra. We showed the recovery of a desired signal that was 35 dB lower in amplitude than a large-signal interferer located at the same frequency. We believe this is already useful for applications in securely transmitting signals hidden beneath an interferer and also for applications in simultaneous transmit and receive. We are presently working to show the recovery and demodulation of multiple (> 2) transmitted signals through further refinements of the optoelectronic filter.

3. References

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